SYMBIONTS AND BIODIVERSITY

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The importance of invertebrate symbionts to our concepts of conservation and biodiversity is demonstrated using Australian freshwater crayfish and their symbionts as a model. Concepts discussed are (1) hosts are also habitats, and (2) conserving biodiversity means conserving symbionts. The case is argued for *Euastacus* to act as 'flagships' to focus our need to preserve invertebrate species and their habitats. □ *Invertebrates, parasites, symbiosis, freshwater crayfish, Euastacus, Cherax, temnocephalan, conservation, biodiversity*

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Symbionts literally are organisms which live together. Attempts to define and prescribe limits to the spectrum of associations found have proven impossible (Price, 1980; Schmidt & Roberts, 1989); parasitism, however, is the most common and easily recognised form of symbiosis in which the parasite, usually the smaller organism, derives benefit from the other, the host. This account highlights the central role of invertebrate symbionts to conservation and biodiversity by using Australian freshwater crayfish and their symbionts as a model, and in doing so places symbiosis at the forefront of the current debate on conservation and biodiversity.

Many people today unfortunately still perceive most symbionts as undesirable, since they frequently compete with us for resources but in our opinion it is now time to consider an objective ecological view of the value of symbionts. Medical and agricultural science wages continual war against pests and parasites, yet van Beneden (1876), reflecting his times, cautioned that even grave diggers have a place in society. Similarly, we think we must begin to acknowledge the value to society of symbionts even though we may not always care to associate with them. We must acknowledge that the diversity of life is vastly enriched by such symbionts - most of which are invertebrates. A prerequisite to their conservation, we believe, is an extension of our concept of habitats: we must recognise hosts as habitats (Horwitz, 1990a).

AUSTRALIAN FRESHWATER CRAYFISH

Haswell (1893) recognised 3 crayfish species on the Australian mainland. These were the spiny or mountain crayfish (*Astacopsis serratus* (Shaw, 1794)) from coastal streams of eastern Australia, the smooth crayfish of inland streams (*Astacopsis bicarinatus* Gray, 1845) and the burrowing crayfish of Victoria (*Engaeus fossor* (Erichson, 1846)).

About 100 species of crayfish on mainland Australia are now recognised (Morgan, 1988; Horwitz, 1990b; John Short, Queensland Museum, *pers. comm.*). Of these, the spiny mountain crayfish *Euastacus* spp. (formerly *Astacopsis serratus*) are without doubt the most endangered (Horwitz, 1990b). Twelve of the 24 species of crayfish listed by Horwitz (1990b) as rare and endangered, are *Euastacus*, and 10 of these are from Queensland. *Euastacus* spp. generally have specific habitat requirements *viz.*, cool, clean water in streams with good canopy cover (Horwitz, 1990b). These conditions occur in southern Australia at sea level, but in Queensland are found almost entirely in forested, mountain regions (Fig. 1; Morgan, 1988). Changing climate over geological time has clearly led to habitat restriction of the *Euastacus* spp., threatening extinction in some cases (Horwitz,1990b). However, human influence has dramatically reduced available habitat further. Regions inhabited by *Euastacus* have yielded the finest rainforest timbers and, once cleared, proved ideal for farming dairy cattle. In Queensland, and in New South Wales according to Merrick (1993), the dairy industry has prospered at the expense of the habitat of *Euastacus*. Today, most rare and/or endangered species of *Euastacus* are restricted to National Parks or forestry regions (Horwitz, 1990b).

CRAYFISH AS HABITATS

Freshwater crayfish are large and most are edible, especially the larger species of *Cherax* which are farmed for food (Merrick & Lambert, 1991). Aquaculture has driven research to determine which invertebrate symbionts (particularly parasites and pathogens) inhabit the three major food crayfish of Australia, *viz. Cherax quadricarinatus* (von Martens, 1868) (= redclaw), *C. destructor* Clark, 1936 (= yabbie) and *C. tenuimanus* (Smith, 1912) (= marron). Consequently our knowledge of the diversity of symbiont suites of cultured crayfish has increased dramatically (Table 1, a-c).

Symbionts of crayfish are diverse and numerous. From over 10,000 published references to crayfish, over 10% of them concern symbionts in 8 different phyla or groups (Hart & Clark, 1987). Furthermore, interactions within a suite of ectosymbionts using crayfish as a habitat are complex (Cannon & Jennings, 1987; Jennings, 1988).

TEMNOCEPHALAN ECTOSYMBIONTS

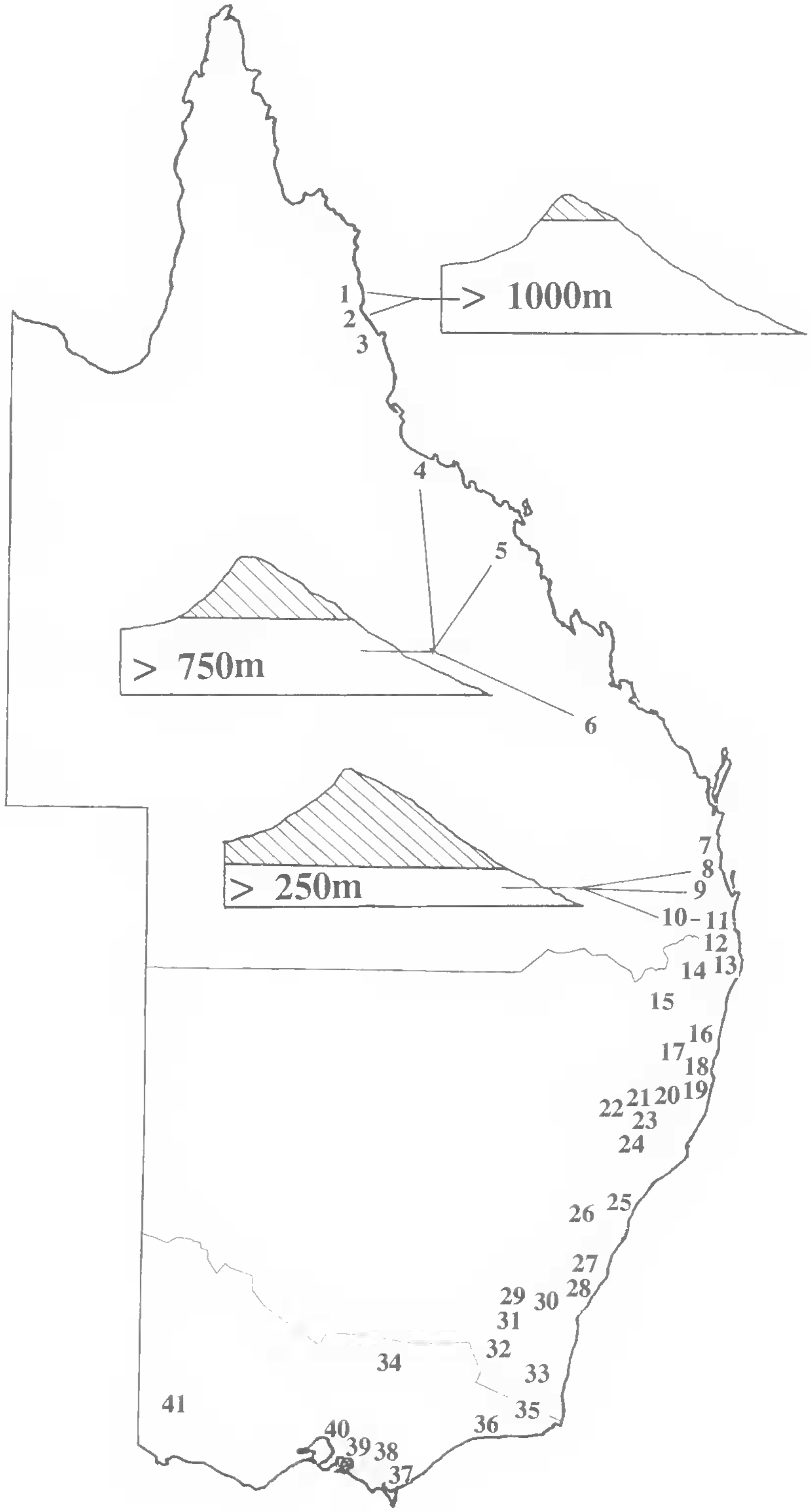
Temnocephalans are the largest symbionts on crayfish. These ectosymbiotic turbellarian flatworms are particularly common on Australian crayfish and have been known for over 100 years (Haswell, 1893). On the 3 crayfish hosts that were recognised then, Haswell (1893) reported 7 species of worms. These were: *Temnocephala fasciata* Haswell, 1888 and *T. comes* Haswell, 1893, as large brown and small white species respectively on *Astacopsis serratus*, *T. minor* Haswell, 1888 as an external inhabitant and *T. dendyi* Haswell, 1893 and *Craspedella spenceri* Haswell, 1893 as gill inhabitants of *Astacopsis bicarinatus* and from *Engaeus fossor*, *T. engaei* Haswell, 1893 externally and *Actinodactylella blanchardi* Haswell, 1893 on the gills.

Although temnocephalans are common on many Australian freshwater crustaceans, most are undescribed. Fourteen species in 3 genera have been recognised from mainland crabs and shrimps (Cannon, 1993a) and 11 proposed new species have been found in the branchial chamber of mainland freshwater crayfish (Cannon &

Table 1 a-c. Symbionts recorded from 3 species of cultured Australian crayfish
* = from laboratory reared crayfish only

(a) REDCLAW Cherax quadricarinatus	
SYMBIONT	REFERENCE
BACTERIA	
Mycobacterium chelonei	Anderson (1990)
Pseudomonas sp.	Pearce (1990)
Vibrio cholera	Eaves & Ketterer (1990, unpublished) in Anderson (1990)
FUNGI	
fungi sp.	Herbert (1987)
?*Achlya* sp.	Herbert (1987)
Achlya sp.	Pearce (1990)
?*Allomyces* sp.	Pearce (1990)
Saprolegnia sp.	Herbert (1987)
Lagenidium sp.	Sammy (1989)
oomycetes sp.	Herbert (1987)
Phythium sp.	Sammy (1989)
Psorospermium sp.	Herbert (1987)
Saprolegnia sp.	Sammy (1989)
MICROSPORA	
Thelohania sp.	Herbert (1988)
CILIOPHORA	
Lagenophrys darwini	Kane (1965)
Lagenophrys lawrii	Kane (1965)
Lagenophrys sp.	Herbert (1987)
Vavraia sp.	Langdon (1989)
Zoothamnium sp.	Herbert (1987)
Epistylis sp.	Herbert (1987)
**Vorticella* sp.	Herbert (1987)
PLATYHELMINTHES	
Craspedella sp. nov.	Cannon & Sewell (unpublished)
Decadidymus gulosus	Cannon (1991)
Diceratocephala boschmai	Cannon (1991)
Didymorchis sp.	Cannon & Sewell (unpublished)
Notodactylus handschini	Cannon (1991)
Temnocephala rouxii	Cannon (1991)
NEMATODA	
nematoda sp.	Herbert (1987)
ANNELIDA	
Stratiodrilus novaehollandiae	Jones (1992)
ARACHNIDA	
mite sp.	Cannon & Sewell (unpublished)

Fig 1. Distribution in eastern Australia of named species of *Euastacus* (after Morgan 1986, 1988, 1989; Merrick, 1993) and *Euastacus* spp. (Morgan, in press) and showing elevations above which they are found in Queensland: (1 *E. robertsi*, 2 *E. fleckeri*, 3 *E. balanensis*, 4 *E. bindal*, 5 *E. eungella*, 6 *E. monteithorum*, 7 *E. urospinosus*, 8 *E. hystricosus*, 9 *E. setosus*, 10 *E. jagara*, 11 *E. maidae*, 12 *E. sulcatus*, 13 *E. valentulus*, 14 *E.* sp., 15 *E. suttoni*, 16 *E. neohirsutus*, 17 *E. simplex*, 18 *E.* sp., 19 *E. hirsutus*, 20 *E.* sp., 21 *E.* sp., 22 *E.* sp., 23 *E. polysetosus*, 24 *E. reductus*, 25 *E. spinifer*, 26 *E. australiensis*, 27 *E.* sp., 28 *E.* sp., 29 *E. crassus*, 30 *E.* sp., 31 *E. claytoni*, 32 *E.* sp., 33 *E. brachythorax*, 34 *E. armatus*, 35 *E. bidawalus*, 36 *E. diversus*, 37 *E. neodiversus*, 38 *E. kershawi*, 39 *E. yarraensis*, 40 *E. woiwuru*, 41 *E. bispinosus*.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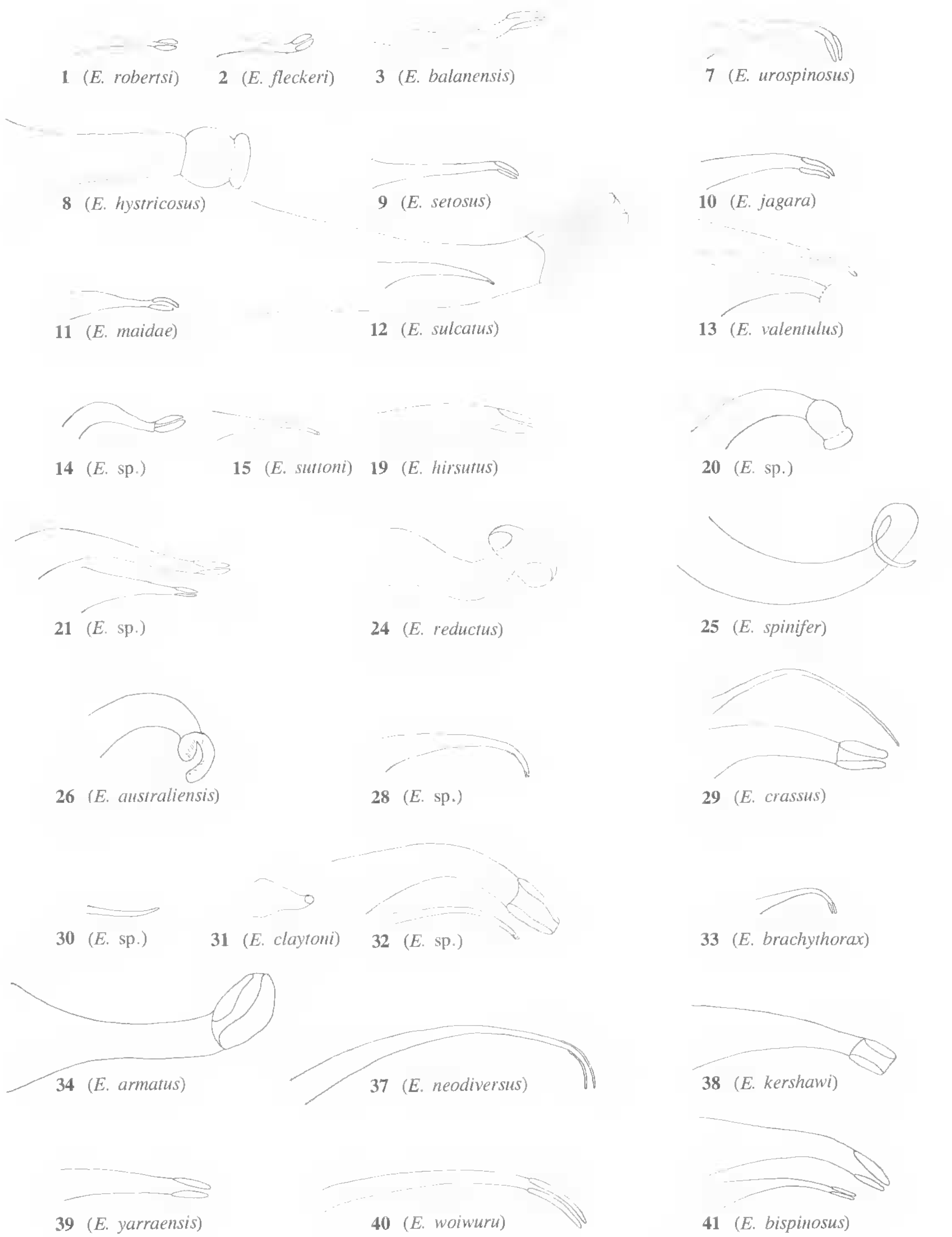

Fig 2. Male organs of temnocephalans taken from *Euastacus* spp. (locality from Fig. 1 and name in parentheses).

Table 1 b, c. (continued) Symbionts recorded from 3 species of cultured Australian crayfish
* = from laboratory reared crayfish only

(b) YABBIE *Cherax destructor*	
SYMBIONT	REFERENCE
BACTERIA	
Pseudomonas sp.	Copland (1981)
FUNGI	
Saprolegnia sp.	Merrick & Lambert (1991)
MICROSPORA	
microsporidia sp.	Langdon (1989)
Thelohania sp.	Carstairs (1979)
CILIOPHORA	
Epistylis sp.	Herbert (1987)
Lagenophrys communis	Kane (1965)
Lagenophrys latispinosa	Kane (1965)
Lagenophrys lingulata	Kane (1965)
Lagenophrys occlusa	Kane (1965)
Lagenophrys setigola	Kane (1965)
Lagenophrys spinosa	Kane (1965)
Lagenophrys willisi	Kane (1965)
Pyxicola jacobi	Kane (1964)
Pyxicola bicalceata	Kane (1964)
rotifer sp.	Kane (1964)
PLATYHELMINTHES	
cestoda sp.	Gardner (unpublished) in Mills (1983)
Craspedella spenceri	Kane (1964)
Diceratocephala sp.	Kane (1964)
Didymorchis sp.	Rohde (1987)
Temnocephala dendyi	Williams (1978)
Temnocephala minor	Williams (1978)
NEMATODA	
nematoda sp.	Mills (1983)
ARACHNIDA	
mite sp.	Kane (1964)
CRUSTACEA	
Notocyther mirrantia	Hart & Hart (1967)
Notocyther syssitos	Hart & Hart (1967)
ostracod sp.	Mills (1989)

(c) MARRON *Cherax tenuimanus*	
SYMBIONT	REFERENCE
FUNGI	
fungi sp.	Evans (1986)
Saprolegnia spp.	Pass & Morrisey (1984, unpublished) in Glazebrook, Owens & Campbell (1985)
MICROSPORA	
microsporidia sp.	Langdon (1990)
Thelohania sp.	Pearce (1990)
CILIOPHORA	
Cothurnia sp.	Evans (1986)
Epistylis sp.	Herbert (1987)
Lagenophrys deserti	Kane (1965)
Vavraia sp.	Langdon (1989)
Zoothamnium sp.	Herbert (1987)
PLATYHELMINTHES	
Temnocephala sp.	Cannon & Sewell (unpublished)
Temnocephala minor	Cannon & Sewell (unpublished)
NEMATODA	
nematoda sp.	Evans (1986)

Sewell, in prep.). We have found large, brown pigmented temnocephalans with 5 tentacles inhabit the surface of most *Euastacus* spp. Although only one species (*Temnocephala fasciata*) has been described (Haswell, 1893), we have found that there is considerable diversity in the shape and/or size of the sclerotic male copulatory organs (the only hard parts of these worms) on *Euastacus* from Cape York, Queensland to the Grampian Range on the border of Victoria and South Australia (Fig. 2). This we believe is strong evidence that there are many undescribed species of temnocephalans on these crayfish.

Smaller non-pigmented worms with 6 tentacles occur on many *Euastacus*: these also await description. In addition, there are other worms from *Cherax* spp. and *Engaeus* spp. (unpublished observations). The Tasmanian temnocephalan fauna was described by Hickman (1967).

BIODIVERSITY AND CONSERVATION

Cultured crayfish are well studied and their recorded symbionts are diverse. At present few symbionts are known from *Euastacus*, but our temnocephalan data suggest that a similar increase in the number of known symbionts would occur should these hosts be regarded as important as those we eat. The biodiversity of symbionts probably will exceed that of their hosts. Rohde (1976) estimated that whereas the fish fauna of the Great Barrier Reef may approach 2000 species, the parasite fauna could be as high as 20,000 species in those fish. Similarly, Price (1980), who considered plants as hosts, found that 92% of all animal species are parasites. Clearly, *conserving biodiversity means conserving symbionts.*

Conserving symbionts has important ecological consequences. Freeland (1993) demonstrated the ecological significance of parasites which can help sustain host populations by dampening their oscillations to reduce the probability of local host extinctions. Also, Horwitz (1990b) warned introductions of foreign crayfish and associated symbionts may lead to loss of unique symbiont fauna. This view has been supported by Cannon (1993b) who reported the native temnocephalan fauna of marron, *Cherax tenuimanus*, has largely been displaced in aquaculture by the pest *Temnocephala minor* which has apparently been introduced via the translocation of its natural hosts *Cherax albidus* Clark, 1936 and/or *C. destructor* into aquaculture with marron.

Thus, symbionts make a major contibution to biodiversity, and their conservation has important ecological implications. We must recognise that even parasitism, as a form of symbiosis, can be beneficial in maintaining biodiversity. Our own attitudes and perceptions have been strongly influenced by observations made during the extensive fieldwork required for this study. We travelled a total of more than 15,000km by road through 5 Australian states in search of *Euastacus* and other freshwater crayfish hosts. Our *modus operandi* was to seek crayfish species in localities where, according to Museum collection records, they had previously been collected. We repeatedly found documented crayfish habitat to be eutrophic, muddy wallows caused by stock having degraded stream banks, destroying riparian vegetation and thereby eliminating habitat and crayfish. Merrick (1993) reported these and related factors as the main threat to the conservation of *Euastacus* in New South Wales. Not only animals are under threat from pastoral practices. Recently, Cheal (1993) concluded from a study of grazing stock in Victoria that 'there was almost total lack of regeneration of trees and shrubs throughout the grazed areas, and their extinction is inevitable if stock grazing is maintained'. Clearly, if we wish to maintain biodiversity in Australia we must espouse a more flexible attitude to primary industries based upon sustainable natural resources. Encouraging evidence exists that outdated practices and attitudes are changing. The Landcare program now boasts 25% of the farming community as supporters (ABC programme - Landcare, 5th Sept 1993).

Essentially, we believe there is the need to limit human population growth. In Australia, the debate on population has been hijacked by historians, sociologists, economists and other 'authorities' (see Ruthven, 1992), who appear ignorant of the biological imperative that a species will exploit its resources and grow until limited, i.e. from disease, conflict or from lack of space, shelter, food or water. The quality of our lives, the nature of our society and our economic structure all ultimately rest on the figure we set for our desired population. In such a dry continent we fear we are perilously close to that limit.

This account has centred upon crayfish of the genus *Euastacus* and their unique position as prominent invertebrate hosts/habitats for a wide diversity of symbiotic invertebrates. As such, these large, often strikingly handsome crayfish could act as 'flagship species' or 'ambassadors' to focus our attention on the need to preserve invertebrate species and their habitat. Indeed, Horwitz (1990b) says 'the freshwater crayfish of Australia rank as one of, if not, the most important groups on which to base a discussion of the conservation of freshwater crustaceans'. We would like to add -'*and* of invertebrates and biodiversity itself'.

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